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N.J. 08405

Controller Evaluation of Initial Data Link Air Traffic Control Services: Mini Study 2 Volume I

Nicholas J. Talotta, et al.

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Final Report

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16. Abstract
This report details the results of Mini Study 2. This Mini Study was conducted at the Federal Aviation Administration (FAA) Technical Center utilizing the Data Link test bed. Initial Data Link air traffic control services were evaluated under part task simulation conditions in order to identify service delivery methods which optimize controller acceptance, performance, and workload.

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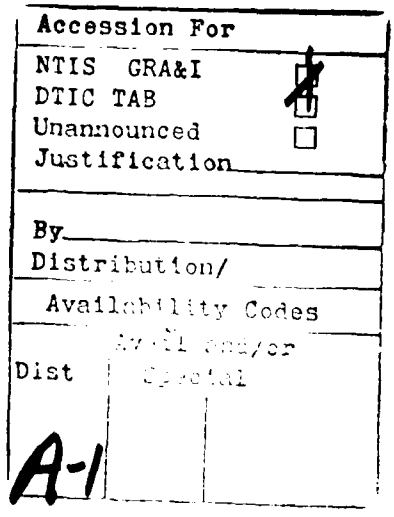
PREFACE

This report documents the second in a series of Federal Aviation Administration controller evaluations of en route air traffic control services planned for implementation on the Data Link system. The report is organized in two volumes.

Volume I contains the main body of the report. It includes a detailed description of the objectives of the study and of the technical approach and test methods that were used. In addition, the combined results of the study, conclusions, and recommendations are presented.

Volume II consists of a set of four appendixes to the report. These appendixes are referenced in Volume I and include documentation of the controller procedures used to deliver the test services, as well as detailed analyses of the data that were collected.



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The planning and execution of the study were the results of cooperative efforts of several members of the Data Link Development Team. In particular, the following individuals played key roles in this research:

Nicholas Talotta, FAA Technical Center - Test Director

Thomas Pagano, FAA Technical Center - Test Coordinator

Haim Gabrieli - MITRE Coordinator

Henry Marek, FAA Technical Center - Test Documentation

William VanCampen, MITRE - Scenario/Script Coordinator

George Chandler, FAA Technical Center - Data Link Pilot/VAX Coordinator

Clark Shingledecker, NTI, Inc. - Human Factors Coordinator

Daniel Kashey, Data Transformation Corporation (DTC) - Host Computer System Software Design

Appreciation is extended to the members of the Data Link Development Team including:

James Merel, DTC
John Evans, DTC
David Sweeney, MITRE
Thomas Zurinskas, FAA Technical Center
F. Paul Zito, FAA Technical Center
Karol Kerns, MITRE
Preston Cratch, MITRE

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This report is the product of inputs submitted by the FAA Technical Center; NTI, Inc.; and The MITRE Corporation.

Special appreciation is extended to the nine air traffic controllers who served as subjects and observers. Without the professional and thoughtful contributions of the following individuals, this study would not have been possible:

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EXECUTIVE SUMMARY

INTRODUCTION.

The Federal Aviation Administration (FAA) Test Plan for the Mode S Data Link defines a two-stage process for controller evaluation of candidate air traffic control (ATC) services. In the first stage, "mini" design studies are being conducted under controlled conditions which simulate only the essential components of controller tasks associated with the services. The goal of these studies is to identify service delivery methods which optimize controller acceptance, performance, and workload. In the second stage, full-scale simulation studies will be performed in order to verify the safety and efficiency of Data Link within the context of realistic operational scenarios. This report presents the results of the second FAA controller Mini Study of en route ATC services developed for implementation on the Data Link system.

OBJECTIVES.

The general purpose of this Mini Study was to extend the results obtained in Mini Study 1 and to evaluate the design of two functions which have been added to the initial package of en route ATC services. The specific objectives of the study were to: (1) define applications and controller procedures for the added free text and menu text services, (2) evaluate the refined altitude assignment and transfer of communication services as well as the text services under more complex test conditions than those employed in Mini Study 1, and (3) provide a preliminary assessment of the impact of Data Link time delays, system degradation, and partial Data Link equipage of controlled aircraft.

DATA LINK OPERATION.

Data Link functions were integrated with the Host Computer System (HCS), operational software, and the Computer Display Channel (CDC) displays. Capabilities of the simulation system included radar data processing, tracking, and flight data inputs. Operational Data Link functions and procedures were integrated with current operational procedures and computer functions. Data base updates followed altitude clearances; handoffs between sectors included radio frequency assignments; and altimeter settings were automatically uplinked.

As dictated by the results of Mini Study 1, the Data Link transaction list display was located on the Plan View Display (PVD), the altitude assignment service was automatically uplinked following a data base update, and transfer of communication uplinks were manually controlled in order to dissociate this service from transfer of control. In all cases, the receipt of a downlinked pilot WILCO response automatically deleted associated list entries.

The two text services were developed as general Data Link functions applicable to a broad range of clearance and advisory messages. For this study, menu text permitted the controller to create a predetermined list

of commonly used ATC messages from which a desired clearance could be selected and uplinked at any time. Free text gave the controller an option to compose and uplink a message in real-time. Text messages were limited to 20 characters.

APPROACH.

Nine full-performance level air traffic controllers from the Dallas/Fort Worth TRACON and the Fort Worth Center participated as subjects and observers in a series of ATC scenarios presented at the work stations in the FAA Technical Center Data Link test bed. The basic test scenario employed fixes and boundaries from the Universal Data Set (UDS) adaptation to create two routes carrying air traffic between two airports. Each route traversed two low altitude departure/arrival sectors adjacent to the airports, and two high altitude sectors located between the low altitude sectors. A total of 24 aircraft travelled through each sector during a 30 minute test run. Variations on the basic scenario were developed to reduce learning effects, and to test the impact of partial Data Link equipage. These variations included the introduction of conflicting overflight traffic, an increase in air traffic density, and a reduction from 100 percent to 20 percent Data Link equipage of the aircraft in the test scenario.

The scenarios were used in a series of test runs designed to review and critique the text service designs and to evaluate the impact of making different combinations of the Data Link services available to controllers. Additional variables tested included the duration for display of confirmatory messages from the pilot, the impact of Data Link system failures in 10 percent of the attempted uplinks, and mixed Data Link equipage in the aircraft fleet. Both projective and actual workload ratings were taken after selected test runs using the Subjective Workload Assessment Technique (SWAT). Preference/acceptability judgments also were solicited from the controllers for each of the Data Link services as implemented for this study. Additional data collection which occurred during debriefing sessions included structured discussions to elaborate on the results obtained in the laboratory, and the completion of a wrap-up questionnaire designed to assess the adequacy of the test scenarios and the operational value of the tested services.

PRIMARY RESULTS.

General controller opinions continued to provide strong positive support for the initial package of en route Data Link services. Working with more realistic ATC problems than those presented in Mini Study 1, the subject controllers concurred that the implementation of appropriately configured versions of the four services will significantly reduce voice frequency congestion while increasing system capacity, safety, and efficiency. Although these projections will require confirmation in operational evaluation research using more complex scenarios and greater air traffic densities, rated workload was unaffected in this study by the substitution of Data Link procedures for current voice procedures. Furthermore, controller workload was not significantly affected by Data Link delays

attributable to antenna rotation lag, a 10 percent rate of uplink failures, or a test environment in which only a fraction of the aircraft were Data Link equipped.

The conclusions of Mini Study 1 were upheld by the present results. The subjects continued to prefer the use of centralized PVD displays of Data Link transaction status, the use of Data Link without redundant voice communication, the necessity for downlinked pilot confirmation, and the use of automatic uplinks, where feasible, to minimize data entries. However, the current test conditions also presented situations which led the controllers to suggest several refinements to the services. In particular, subjects indicated that transfer of communication must be modified so that uplink authority transfers with the assignment of a new radio frequency, and that altitude assignment should permit the controller to selectively inhibit uplinks. Results for the text services showed that the controllers preferred to use menu text for control clearances and that it must, therefore, be designed to permit automatic system updates when needed. Free text was preferred as a backup for radio failures and as a method for transmitting advisories and other non-control messages.

Two issues which emerged during Mini Study 1 surfaced under the present testing conditions. The first of these is a requirement to develop Full Data Block (FDB) displays for Data Link transactions in order to reduce the display scanning demands of monitoring Data Link transactions. The second is the need to develop a method for permitting flexible control over uplinks, NAS updates, and FDB updates. This is due to the fact that ATC practices in different en route centers require that it be possible to selectively control these events for each transaction.

RECOMMENDATIONS.

Based on the results outlined above, several modifications to the design of the four tested services are recommended prior to full-scale, operational evaluation research. Briefly, a high priority should be assigned to the development of FDB displays of key transaction states for Data Link services. These displays should be easily interpretable and should supplement the transaction status list. Equally high priority should be devoted to the development of flexible control over the destinations of keyboard and trackball data entries for control clearances delivered by Data Link.

In addition, it is recommended that provision be made for linking menu text services to the remainder of the ATC system so that control clearance menu text uplinks can selectively update NAS, the FDB, or both. Transfer of communication and altitude assignment also should be modified in accordance with the present results in order to make these services compatible with the full range of ATC procedures employed in current field environments.

Finally, in order to identify any remaining limitations in the modified service designs, it is recommended that emphasis be given to the development of more complex ATC scenarios for the operational evaluation, and that this research reexamine the potential impact of Data Link failures, transmission delays, and partial equipage environments.

1. INTRODUCTION.

1.1 PURPOSE.

This document presents the results of the second in a series of Federal Aviation Administration (FAA) air traffic controller evaluation studies of en route air traffic control (ATC) services designed for implementation in the Mode Select Beacon System (Mode S) Data Link system. Specifically, this study was conducted to evaluate controller procedures for the free text and menu text services. In addition, this study provided an opportunity to obtain further controller inputs regarding the design of the altitude assignment and transfer of communication services tested in the first controller evaluation (Talotta, et al., 1988), and to estimate the impact of system delays, system degradation, and partial Data Link equipage on controller workload.

1.2 BACKGROUND.

1.2.1 Mode S Data Link

The Mode S is a secondary surveillance radar which will replace the current Air Traffic Control Radar Beacon System (ATCRBS). The ATCRBS uses a ground-based rotating antenna that transmits continuous radio frequency (RF) interrogations to which a transponder equipped aircraft will respond. The replies provide the ATC system with an aircraft identification code or the aircraft altitude. Aircraft location information is provided by the rotational position of the antenna and the transponder response delay at the time a reply is received.

The Mode S will provide the same functions as the ATCRBS, but will do so more accurately while offering the additional capability of transmitting digital information across a two-way, air-ground Data Link. These enhancements are possible because each aircraft will be assigned a unique address code which will be used in the system's interrogations to select only the requested aircraft to respond. The primary components of Mode S are illustrated in figure 1.

Because of its flexibility and capacity, the Mode S Data Link promises to be a key to increased automation of the ATC system, and, therefore, has the potential to significantly enhance ATC safety and productivity. One of the primary ways in which this potential will be achieved will be through the impact of Data Link on the tasks of the air traffic controller.

The first service to be provided by Data Link will be automated delivery of weather advisories to aircraft. This function alone will reduce the controller's task load by eliminating any requirement to verbally relay weather data to pilots via radio. However, the accelerated Data Link program also calls for the Data Link to mediate a variety of primary ATC services which are currently accomplished in a completely manual fashion using voice radio. The proposed ATC services will include transfer of communication, clearance deliveries, inflight plan amendment, and a variety of other transactions among controllers, pilots, and automated systems.

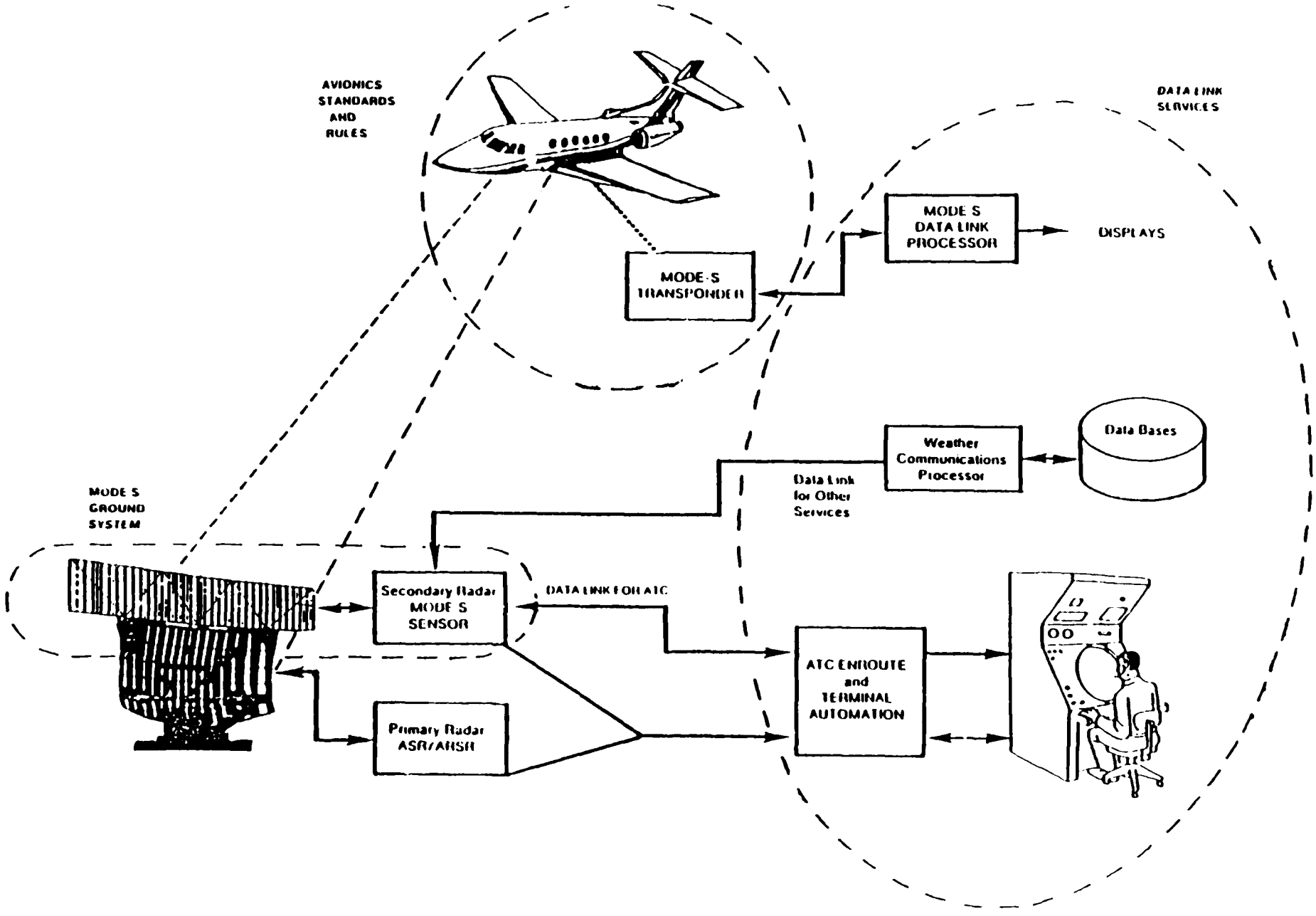

FIGURE 1. MODE S SURVEILLANCE AND DATA LINK

The ultimate success of Data Link is critically dependent on the extent to which it is employed to produce a system that is well integrated with the human operators who will be required to control and supervise its function. Because Data Link will profoundly affect the manner in which air traffic controllers accomplish their duties, it is imperative that service delivery procedures, and the displays and controls used to interact with the system, are designed with careful consideration of their impact on the performance capabilities of the controller. The intent of the controller evaluation reported in this document, and of other studies in this program, is to insure that controller workload, performance, and acceptance are used as primary inputs to the development and implementation of the Data Link system.

1.2.2 En Route Data Link Services and Functions.

The initial package of ATC functions scheduled for implementation in the Data Link system includes: altitude assignment, transfer of communication, free text, menu text, and possibly en route minimum safe altitude warning (EMSAW). The altitude assignment service will transmit digital altitude clearances to an aircraft display. This service may be used as a substitute for the current voice radio altitude clearance. Transfer of communication is presently accomplished by a voice contact with the pilot following a transfer of control between sectors. Using Data Link, this service will permit the transferring controller to send a digital message to the aircraft which will inform the pilot of the radio frequency on which the receiving controller will be communicating. EMSAW is a warning service relayed to pilots by ATC when the system predicts that predetermined minimum flight altitudes will be violated. Under Data Link, this service may be provided by sending the warning directly to a cockpit display, rather than by a voice radio message. This service was not evaluated in the study.

The two text services are more general Data Link functions which are potentially applicable to a broad range of clearance and advisory messages. Free text will provide the controller with a capability to engage in unconstrained ground-air communications with Data Link equipped aircraft. This service will permit controllers to compose and uplink textual material in real-time, thereby providing an emergency back-up channel for voice transmissions. (Free text was originally conceived as a method for controlling aircraft experiencing emergency radio failures.) Free text messages are presently not retained after being sent. The menu text service is a Data Link function which will permit controllers to create and retain a customized list of ATC instructions, each of which could be selected and uplinked as needed. The primary purpose of the menu text service is to offer controllers a simplified method for uplinking common ATC messages which are used repetitively in specific sectors.

1.2.3 Results of Mini Study 1.

The first controller evaluation study of the initial package of en route Data Link services addressed transfer of communication, altitude assignment, and EMSAW described above (Talc a, et al., 1988). In Mini Study 1, 10 en route air traffic controller: articipated as subjects and observers in a series of highly simplified A scenarios presented at work

stations in the FAA Technical Center Data Link test bed. These scenarios presented each controller with three aircraft which received the services under evaluation. Controller activities were highly scripted, and no attempt was made to simulate an actual ATC problem. The purpose of the test was to permit the controllers to evaluate several display and procedural options for each of the three services.

Both Plan View Display (PVD) and Computer Readout Device (CRD) locations were tested for presentation of Data Link transaction status. This list display provided information regarding the service content, the aircraft receiving the service, and the current status of the transaction. Thus, the display indicated when a message was ready for uplink (HELD), when it had been SENT, whether a technical acknowledgement had been received from the aircraft transponder (DELIVERED) and any pilot response or response failure (WILCO, UNABLE or FAI).

In addition to these display options, several procedural variations were tested. Uplinks were either initiated manually by a keyboard entry, or were sent automatically as a result of a National Airspace System (NAS) event associated with an altitude assignment entry, transfer of communication, or the detection of an EMSAW altitude violation. Additional test runs examined requirements for voice communications between the pilot and the controller, requirements for a confirmatory response from the pilot, and manual vs. automatic deletion of transaction list entries once a transaction had been completed.

Controller responses to the test options were assessed using projective workload scales and preference/acceptability ratings following each test run. In addition, structured group discussions and a wrap-up questionnaire were administered to elaborate on the quantified results and obtain individual opinions of the Data Link services.

General controller responses to Data Link were strongly positive. Specific results regarding the service design options indicated that the PVD display was preferred over the CRD display of Data Link transaction status. The subjects also indicated that further improvements may be achieved by the development of a Full Data Block (FDB) indication of key transaction states.

In general, automated procedures produced lower workload and higher preference ratings than those which required the controllers to manually initiate uplinks and delete completed transactions from the status list. However, the subjects also indicated that some services (e.g., transfer of communication) must be separated from the event which is used to generate the uplink (e.g., acceptance of a hand-off). Therefore, manual options must be made available for such situations.

Although the continued availability of a reliable voice radio channel was considered essential, radio communications which were redundant with data link messages were not preferred and produced higher projected workload ratings than "Data Link only" conditions. In addition, some form of confirmatory response to an uplink was considered mandatory for all services, and a downlinked pilot response was found to be a valid method for providing this information to the controller.

1.3 DATA LINK TEST BED.

Both the initial study discussed above, and the research reported in this document were conducted in the Data Link test bed facility located at the FAA Technical Center. The Data Link test bed was assembled to provide both engineering testing and evaluation capabilities for Data Link services during controller-in-the-loop simulation. Figure 2 presents a functional diagram of the main components of the test bed and their interconnections. A key feature of the test bed facility is that it permits development of Data Link services on actual en route ATC controller workstations and associated computers rather than on an emulation system. As a result, it will be possible to implement the final configurations for the tested services in field test sites without extensive functional modification.

During each run of the simulation study described in this report, four subject controllers were presented with simulated radar data and ATC system information from the Host Computer System (HCS). The voices and Data Link inputs of aircraft pilots were provided by four controllers who were not participating as subjects in the run. The Dynamic Simulation system (DYSIM) was used to control aircraft activity. A VAX 11/750 computer generated all Data Link outputs and permitted flexible variations of Data Link procedures required by the test design.

2. TEST DESCRIPTION.

2.1 OBJECTIVES.

The overall test plan for controller evaluation of Data Link ATC services calls for research to achieve two major objectives. First, the evaluation studies must determine the operational procedures and display methods for each of the subject services. Second, these studies must evaluate the integration of the Data Link services with other controller activities and ensure the acceptability of controller and system performance under operational conditions.

These objectives imply that optimization and validation of Data Link ATC services will require research to examine a large number of human factors design variables, as well as the impact of various operational and environmental factors. In order to address these parameters in an efficient fashion, a two-stage evaluation process was developed.

In the first stage, controlled, part-task simulation studies are being conducted with en route controllers to reduce the number of design alternatives to a reasonable set. These "mini" studies involve the formal testing of display and procedural options for each service, as well as structured discussions designed to elicit expert controller opinions. The formal criteria for option evaluation in these mini studies are measures of controller workload and acceptance.

In the second stage of the evaluation process, operational evaluation studies will be performed in the context of full-scale ATC simulation. The specific goal of this stage will be to confirm the optimality of the design of each Data Link service, and to verify the safety and efficiency

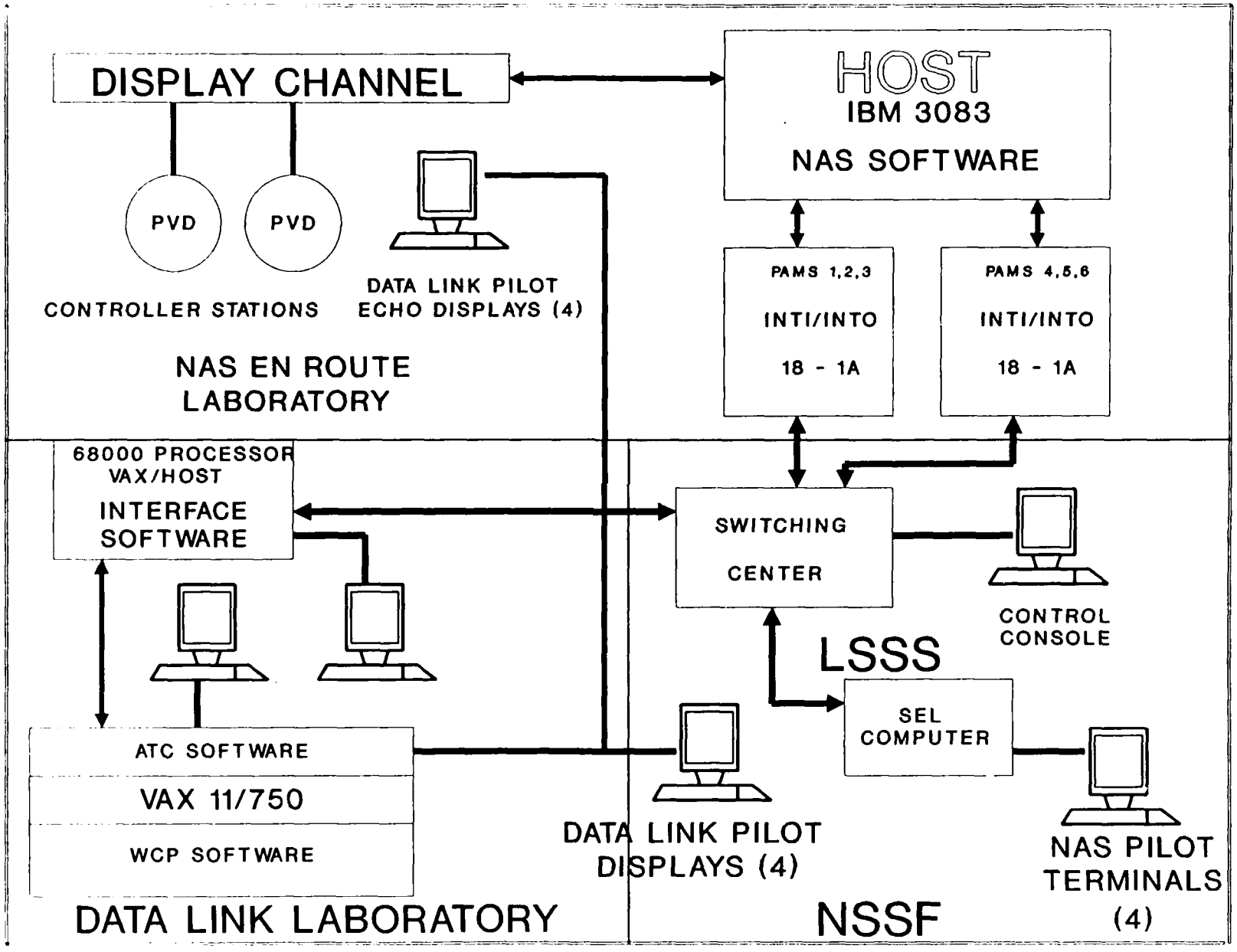

FIGURE 2. ATC DATA LINK TEST BED

of Data Link under various operational conditions. Operational evaluation studies will assess overall system effectiveness, performance, and controller workload within ATC test scenarios representing both nominal and high levels of controller task demand.

The study reported here is the second Mini Study conducted under the test plan outlined above. The general purpose of the study was to extend the results obtained in Mini Study 1 and to evaluate the design of the remaining two functions included in the initial package of en route ATC services. The specific objectives of Mini Study 2 are listed below:

a. Define applications and controller procedures for the free text and menu text services and functions.

b. Evaluate the refined altitude assignment and transfer of communication services as well as the text functions under more realistic test conditions than those employed in the first Mini Study.

c. Provide a preliminary assessment of the impact of Data Link time delays, system degradation, and partial Data Link equipage of controlled aircraft.

2.2 TEST APPROACH.

The approach that was adopted to meet the objectives of this Mini Study involved the participation of nine air traffic controllers in a series of 30-minute ATC scenarios presented at the work stations in the Data Link test bed. Each test run required four of the subjects to actively control individual sectors of en route airspace. Unlike the first Mini Study, the scenarios used in the test runs presented the subjects with a realistic air traffic control problem involving the movement of aircraft between two airports. The subjects alternated as active controllers and DYSIM pilots in order to permit each participant to experience all test conditions.

Following each test run, the controllers were asked to provide workload ratings and, in some cases, preference evaluations for the test options. As in Mini Study 1, these formal ratings were supplemented by debriefing interviews and a wrap-up questionnaire administered during post-test sessions.

The rationale underlying the testing approach was to utilize the test bed to produce realistic representations of service design alternatives and differing air traffic and Data Link conditions. The goal of the study design was to permit the subjects to integrate these objective experiences with their general knowledge of the en route ATC environment in order to provide data which would guide the design and refinement of the Data Link services under evaluation.

2.3 TEST CONDUCT.

2.3.1 Subjects.

The subjects for this study were nine current, full performance level (FPL) air traffic controllers from the Dallas/Fort Worth Terminal and the Fort Worth Center. All of the controllers had participated as subjects in Mini Study 1 and, therefore, were familiar with the evolving Data Link services and the testing methods used in the Data Link program.

Of the nine controllers, eight served as subjects in the formal test bed evaluation. The remaining subject acted as an observer during data collection in the test bed, and provided inputs only to the debriefing interview and wrap-up questionnaire items. The subjects who participated in the formal testing had an average of 15.7 years experience as FPL air traffic controllers.

2.3.2 Test Configurations for the Data Link Services.

The displays and procedures used for the Data Link services evaluated during this study were primarily based on the findings of Mini Study 1. As dictated by those results, the Data Link transaction list display was located on the PVD. In addition, the altitude assignment service was implemented in the automatic mode, while transfer of communication was uplinked manually in order to dissociate this service from the transfer of control. In further accordance with the results of Mini Study 1, UNABLE responses from the pilots were displayed as FAI in the transaction status list, and WILCO responses served to automatically delete the appropriate line from the transaction status list.

The new text functions tested in this study were designed according to the general guidelines derived from the previous services. The menu used for the menu text function was constructed by the controller using the work station keyboard and was displayed as a list on the PVD. Messages were selected from the menu for uplink by entering an identifying number on the keyboard or by trackballing the menu text message number. The content of menu text and free text messages (20 characters maximum) was indicated in the transaction status list by displaying the first six characters of the message.

Detailed procedural instructions for creating and uplinking text messages and for providing the altitude assignment and transfer of communication services as configured for this study are presented on the Data Link En Route Controller Chart shown in appendix D.

2.3.3 Test Scenarios.

The basic test scenario constructed for this study used the Universal Data Set (UDS) adaptation. Fixes and boundaries were selected from UDS to create two routes. One of these routes carried outbound traffic from an airport identified as Philadelphia (PHL) through a low-altitude departure sector, across two high-altitude sectors, and down to a low-altitude arrival sector at an airport identified as Atlantic City (ACY). The second route completed the loop between the two airports, transversing the

same four sectors in the opposite direction. The air routes and sector boundaries are shown in figures 3 and 4.

The basic scenario included nine flights leaving from ACY to PHL and nine flights from PHL to ACY with all aircraft flying at a speed of 400 knots. The initial flights departed from each airport simultaneously, with five additional flights departing at 3-minute intervals. These flights appeared on the PVD's at 12,000 feet, as if they already had been transferred from the terminal facility to the Air Route Traffic Control Center (ARTCC). Three additional flights were initiated en route at the start of the scenario to provide early traffic control opportunities to the high level sectors. The three flights on the PHL-ACY route were initiated at fixes EC2, E2B, and F2A at flight levels (FL) FL250, FL270 and FL240, respectively (see figure 3). The three en route flights on the ACY-PHL route were initiated at fixes F2G, G2F, and E3A at FL260, FL260, and FL240, respectively.

Three versions of this scenario were used during the testing sessions. During the preliminary test runs used to demonstrate the text services and obtain an informal evaluation of their design, the Basic scenario as described above was employed. All aircraft were Data Link equipped. The formal test runs were conducted with the enhanced versions of this scenario described below.

The Overflight scenario was identical to the Basic scenario with the exception that overflight traffic was introduced on routes and at altitudes which would interfere with the flights arriving and departing from the two airports in both the low and high altitude sectors. The routes for the overflight aircraft are shown in figure 3 as dashed lines. All overflight traffic traveled at a speed of 300 knots. At the start of the scenario, the first of 12 overflight aircraft appeared on the eastern side at fix F2E. The remaining flights from the eastern side appeared at 3-minute intervals. Nine additional overflights appeared at fix D2C on the western side following the same 3-minute interval schedule. The altitudes for all overflights were varied between the high and low sectors.

The Mixed Equipage scenario contained all the features of the Overflight scenario described above. However, only a portion of the aircraft in the scenario were Data Link equipped. In addition, the density of the traffic on the two air routes was higher than that in the Basic and Overflight scenarios. The 11 Eastern Airlines and American Airlines aircraft included in the scenario were designated as Data Link equipped aircraft. All of the remaining 34 aircraft were non-equipped. A diamond symbol was displayed as the first character in the aircraft identification line of the FDB to indicate the availability of Data Link for communications with the equipped flights.

Air traffic density was increased in the Mixed Equipage scenario by adding aircraft to the air routes. This manipulation decreased the initial separation between aircraft to approximately 1.5 minutes. In addition, the speeds for each aircraft on the air routes were varied between 250 and 400 knots.

MINI STUDY
AIRCRAFT ROUTING

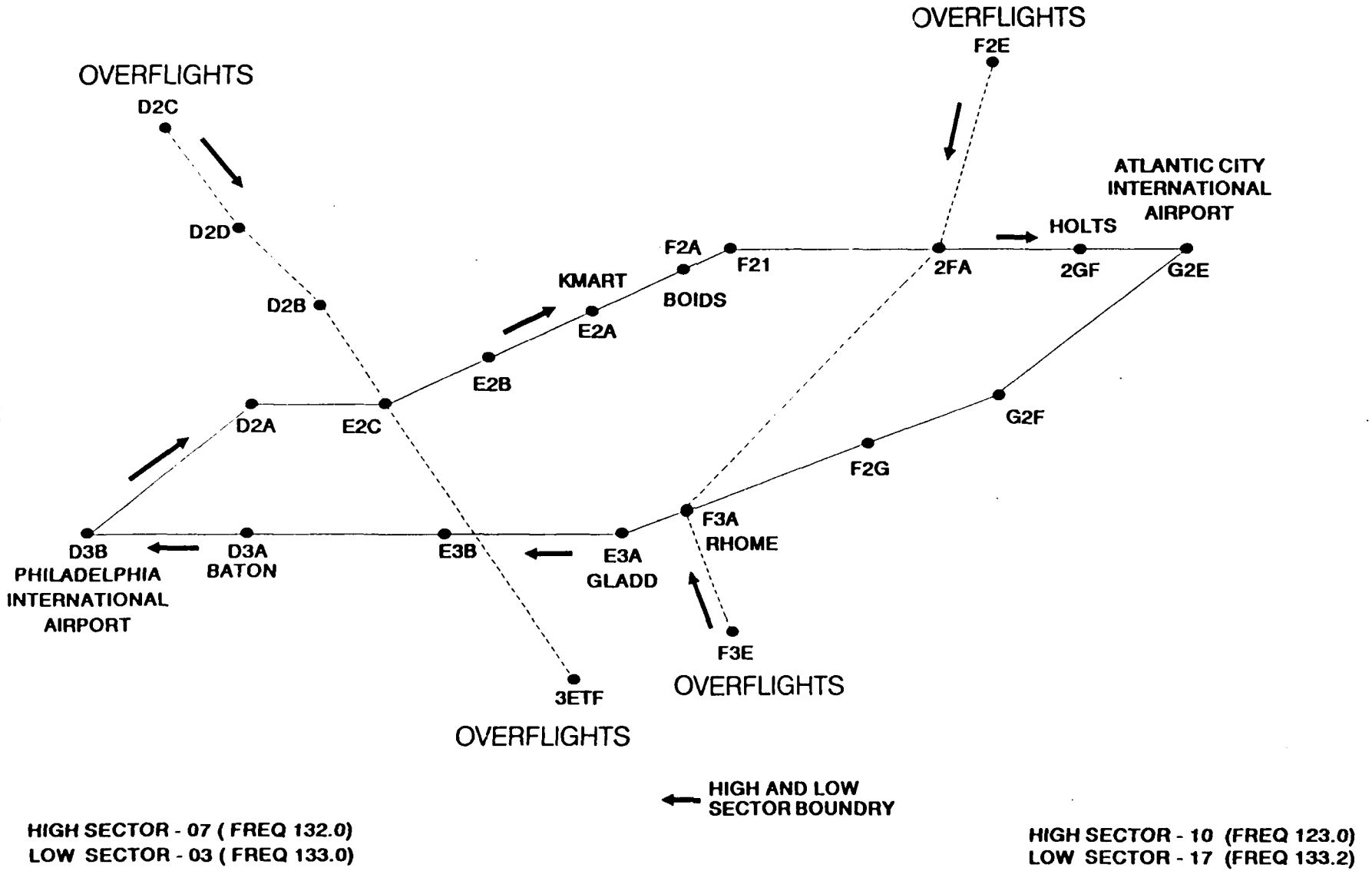

FIGURE 3. TEST SCENARIO AIRCRAFT ROUTING

AIRSPACE SECTORIZATION

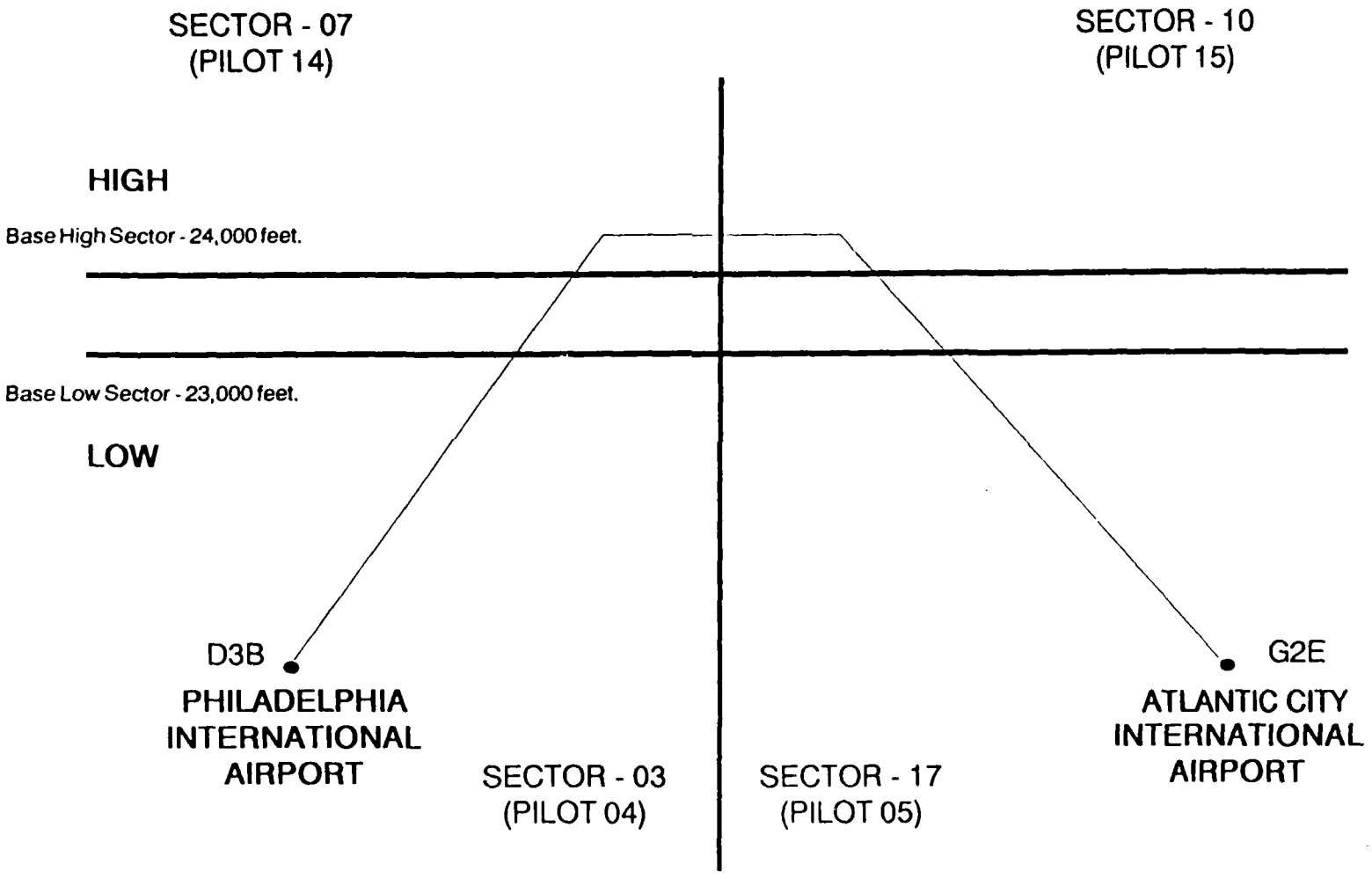

FIGURE 4. TEST SCENARIO SECTORIZATION

The object of the basic scenario development, as well as that of the enhanced versions, was to create an ATC environment in which the services and functions under evaluation could be exercised in a realistic manner. The primary purpose of the additional task load manipulations contained in the Overflight and Mixed Equipage Scenarios was to minimize the impact of over learning effects on controller judgments of the Data Link services.

2.3.4 Test Procedures.

This Mini Study was conducted over a 3-day period. The first half-day was used for subject prebriefing and familiarization, while the remaining time was devoted to data collection.

The prebriefing session consisted of a series of presentations designed to acquaint the subject controllers with the services under evaluation and the test plan. Since all of the controllers had served as subjects in Mini Study 1, the briefings were focused primarily on procedures for the two text services and on a description of the test scenarios. Additional briefings reviewed the results of the first Mini Study and the subjective workload and preference/acceptability rating scale methods that had been used for data collection in that study. Identical rating methods were used in the present study.

Data collection activities for the study were divided into two major parts. The first part consisted of an initial review and critique of the free text and menu text functions. During this session, each subject completed two test runs at the work stations in the Data Link test bed to evaluate operating versions of the text services. The Basic scenario without overflight traffic was used in these test runs in order to simplify the ATC problem and allow the subjects to thoroughly examine the service procedures and displays. Although the primary purpose of these simulation runs was to stimulate debriefing discussions regarding menu text and free text, they also served as training sessions for subsequent formal testing in the second part of the study.

A secondary objective of the first part of the study was to identify an appropriate duration for a display of confirmatory pilot responses to Data Link messages. The results of Mini Study 1 indicated that items on the Data Link transaction status list should be deleted automatically upon receipt of a pilot WILCO downlink. However, the results did not indicate whether the display should be deleted immediately or should remain available for inspection for a brief period of time. To address this issue, each subject completed one simulation run in which the WILCO response deleted the list entry immediately, and a second run in which the response display persisted for 12 seconds after receipt of the WILCO. The preference/acceptability scale shown in appendix B was used by the subjects to evaluate these display persistence options.

Primary data collection for the first part of the study was conducted during a group discussion and debriefing which followed the test bed runs. This session was structured by presenting the controllers with a series of questions on individual overhead projection slides. Each controller was

given a printed copy of the slides in order to record his responses and comments. The primary issues addressed during the debriefing were potential applications for the text services and service design parameters. The detailed contents of the debriefing slides are contained in appendix A.

The second part of this Mini Study consisted of a series of formal data collection runs in the Data Link test bed. Each of the subjects controlled air traffic in five test runs which were presented in the order in which they are described below. Runs 1 to 4 were conducted using the Overflight scenario, while run 5 was conducted using the Mixed Equipage scenario.

Run 1 - Baseline/Current System:

In this run, the subjects controlled the air traffic in the 30-minute test scenario using contemporary ATC procedures and voice radio to communicate with pilots. No Data Link services were available.

Run 2 - Initial Data Link Services Only (Altitude Assignment and Transfer of Communication):

This run was identical to Run 1 above, with the exception that the subjects were instructed to perform all altitude assignment and transfer of communication tasks using Data Link. The services were configured in accordance with the results of Mini Study 1 as described in section 2.3.2 of this report. Voice communication channels were available to the subjects at all times, and were used to accomplish all other ATC services. All uplinks were completed successfully and acknowledged by the simulation pilots using a downlink. In addition, for this condition and all subsequent runs, antenna rotation delays were simulated for Data Link transactions. Thus, a randomly distributed, 0- to 6-second delay was added to the ground-air turnaround time for each uplink.

Run 3 - Full Data Link Services (Altitude Assignment, Transfer of Communication, Free Text, and Menu Text):

This test run was identical to Run 2 above, with the exception that the free text and menu text services were available to the subjects in addition to the altitude assignment and transfer of communication services. Each controller was permitted to devise a customized set of menu text messages appropriate to his assigned sector prior to the test run. The use of both text services was left to the discretion of the controller. In all cases, the controllers were encouraged to use the available Data Link services whenever they were applicable.

Run 4 - Full Data Link Services - 10 Percent Technical Acknowledgement Failure:

This condition made all four Data Link services available as described above. However, in order to determine the impact of Data Link system failures, an average of 1 in 10 uplinks resulted in a failed technical acknowledgement from the simulated aircraft transponders and associated electronic equipment. This failure was displayed as a No Acknowledgement

(NAK) on the appropriate line of the transaction list. The occurrence of a NAK required the controllers to repeat the uplink or contact the pilot by voice radio.

Run 5 - Full Data Link Services - Mixed Equipage:

The final test condition employed the Mixed Equipage scenario described in section 2.3.3 in order to assess the effects of only partial equipage of the aircraft fleet. To simulate the operational environment at early stages of Data Link system implementation, only 11 of the aircraft (20 percent) in the scenario were capable of receiving Data Link communications. As noted in section 2.3.3, this test run also included a decreased initial separation among aircraft in comparison to the first four runs. As in run 4, approximately 10 percent of uplinks resulted in a failed technical acknowledgement.

Following each of the test runs the subjects completed individual workload and, in some cases, preference/acceptability ratings. After all test conditions had been completed by all subjects, a second group discussion debriefing session was conducted. The subjects also completed individual wrap-up questionnaires during this final debriefing session. The assessment techniques used for the ratings, interview, and questionnaire are described in the next section of this report.

2.3.5 Data Collection.

Data collection for the second part of this Mini Study was conducted using objective measures of Data Link activity and subjective ratings of workload and preference taken after the test runs. In addition, a final debriefing discussion and a wrap-up questionnaire were used for data collection in a post-test session.

The workload and preference scales were identical to those used in Mini Study 1. In that study, the scales were used to determine the impact of different procedural and interface design options on controller responses. In the present study, these options were fixed, and the primary focus of the research was on the effects of various mixes of Data Link services and of limited operational variations in a specific simulation scenario. As a result, the application of the rating scales was somewhat different.

The basic workload rating technique used in the Data Link mini studies is known as the Subjective Workload Assessment Technique (SWAT). This rating method permits a subject to quantify the workload of an ATC situation by checking the appropriate descriptor on each of three, 3-point scales. The individual scales refer to time load, the level of mental effort required, and the degree of psychological stress experienced. The SWAT rating scale is described more fully in appendix B.

In this Mini Study, two versions of SWAT were used. The basic SWAT version was used by the controllers to provide ratings of the workload actually experienced by the controllers during each formal test run. Thus, the SWAT ratings permitted comparisons of workload differences between current controller procedures and Data Link procedures within the

context of the specific simulation scenarios used in this study. A projective application of SWAT (PROSWAT) was used after selected runs to permit controllers to project the workload that would be associated with each of the tested services on a moderately busy work day at their normal control positions.

Both SWAT and PROSWAT ratings were transformed to single interval values on a 0 to 100 combined workload scale. The mapping of the time, effort, and stress ratings to the interval scale was accomplished using conjoint measurement and scaling analysis of SWAT card sorts performed by each of the controllers during Mini Study 1. The purpose of the sorting task is to tailor the workload scale to each controller's conception of how the three factors combine to produce different levels of workload. A more complete description of the card sort analysis is presented in Talotta, et al., 1988.

Preference/acceptability scales were also completed after selected test runs to assess subject preferences for each Data Link service as implemented for this study. The form used to make these ratings is shown in appendix B. Briefly, this form required the subjects to determine whether the service implementation was acceptable or completely unacceptable. If acceptable, the controller provided a preference rating ranging from 1 (highly preferred) to 7 (acceptable, but not preferred).

In addition to these rating scales, objective measures of Data Link usage were automatically collected by test bed computers during each test run. These measures included tabulations of the number of completed transactions for each service, as well as the number of failed uplinks.

Two additional data collection techniques were employed during the final debriefing session. The first of these was a structured discussion similar to that used during the first part of the study. Each question was presented on an overhead projection slide, and subjects were given printed copies of the slides to record their comments. The primary purpose of the structured discussion was to elaborate on the results of the test bed runs and to generate potential solutions to any detected problems. The questions included in this session are presented in appendix A.

The second measurement instrument used during the debriefing was a wrap-up questionnaire (see appendix C). The questionnaire covered issues regarding the adequacy of the simulation scenarios, the operational value of the services tested, and their impact on the controller's task.

2.3.6 Data Reduction and Analysis.

Ratings of controller workload and preference were analyzed using standard tests of statistical significance appropriate to the measurement scale characteristics of the data collected. Because of the interval scale nature of the SWAT and PROSWAT scores, these data were analyzed using parametric tests. Nonparametric methods were used in the analysis of the ordinal preference ratings.

The 7-point rating data obtained from the wrap-up questionnaire were evaluated using a Student's t procedure designed to evaluate the significance of differences in ratings from the scale midpoint and from the grand mean ratings.

All remaining narrative responses obtained during the debriefing session were summarized to produce concise descriptions of the types and frequency of occurrence for each comment received. In all cases, the goal of these descriptive analyses was to determine the strength and direction of controller opinions regarding the study issues.

3. TEST RESULTS.

The detailed results obtained with the assessment techniques described above are contained in three appendixes to this report. Analyses of the workload and preference/acceptability ratings and of the recordings of Data Link transactions are presented in appendix B. An analysis of the results of the group debriefing discussions is presented in appendix A. Appendix C contains the results of the final wrap-up questionnaire.

This section of the report draws upon the contents of all three appendixes to address findings which are pertinent to each of the following topics.

3.1 WILCO DISPLAY PERSISTENCE.

A preliminary issue addressed during the first part of this study was the time needed by controllers to determine whether a Data Link transaction had been successfully completed. No significant difference was detected in controller preferences for the 0- and 12-second optional durations for display of a WILCO from a pilot in response to an uplink. Examination of the preference ratings and the results of the wrap-up questionnaire showed that the subjects were evenly split in their choice of an immediate or delayed cancellation of this confirmatory response.

Discussions conducted during the first debriefing session indicated that this split opinion was motivated by two conflicting concerns. Essentially, although an extended display persistence ensures that the controller will be aware of the successful completion of a Data Link transaction, it also tends to add to clutter on the transaction list display. Those controllers who preferred immediate deletion of a transaction line upon receipt of the WILCO also appeared to prefer minimal presentation of transaction status messages (i.e., failures only rather than SENT, DELIVERED, etc.).

One implication of this result is that a phased introduction of assigning the responsibility for Data Link to ATC computer systems may be required to meet the needs of different controllers. Early in the implementation process, controllers may be required to monitor and verify all stages of Data Link transactions. However, as system confidence is attained, only displays of transaction failures may be needed for verifying accurate communication via Data Link. Alternatively, it may be necessary to provide controllers with both an easily interpreted minimal display of

essential transaction status information in the FDB, and an optional list display containing sufficient information to track each stage of a Data Link transaction.

While this design issue will require further examination in future research, the compromise WILCO display persistence of 6 seconds used during the second part of the current study was found to be acceptable to the subject controllers.

3.2 EVALUATION OF THE SERVICE IMPLEMENTATIONS.

3.2.1 Controller Workload During the Simulation Test Runs.

The SWAT ratings collected after each test run were used to assess the actual workload experienced by the subjects while controlling traffic in the context of the specific simulation scenario used in this study. A primary finding derived from the analysis of these ratings was that neither the introduction of the altitude assignment and transfer of communication services nor the addition of the menu text and free text functions produced a significant increase or decrease in controller workload over current, non-Data Link procedures.

While this result supports the operational suitability of the initial package of Data Link services, it should be noted that the test subjects felt that the overall traffic load of the test scenario was low in comparison to their normal ATC work environments. Therefore, these findings may be subject to change when the services are tested in more complex operational that, even at the low level of subject training and familiarization employed in this study, the controller tasks involved in delivering the tested services had no demonstrable negative impact on perceived workload.

3.2.2 Transfer of Communication.

As suggested by the results of Mini Study 1, this service was implemented in the manual mode in order to permit controllers to delay the uplink of a new RF after a transfer of control had been completed.

Despite the comparatively low workload ratings assigned to this service, results of the debriefing discussions indicated that further refinement of transfer of communication will be required prior to the operational evaluation study. Specifically, the service design used in this study transferred Data Link communication capability to the receiving controller upon acceptance of the hand-off. This procedure violates current ATC practice in which voice communication responsibility remains with the transferring controller until the transfer of communication has been completed. In order to bring Data Link procedures in line with this standard, appropriate restructuring will be required to transfer uplink authority only after the transfer of communication has been completed and confirmed by a pilot WILCO downlink.

3.2.3 Altitude Assignment.

Preference ratings showed that the automatic uplink of this service would be less desirable than would have been predicted from the results of Mini Study 1.

As indicated by the debriefing results, the relatively poor performance of altitude assignment in this study was primarily due to the presentation of an operational problem in the test scenarios that required control actions in which coupling of a NAS assigned altitude update, an FDB update, and an uplink would be unacceptable. In the current version of altitude assignment these three events occur simultaneously for all situations.

Suggestions from controllers for alleviating this problem reinforced the results of Mini Study 1, which indicated that full control over the destinations for data entries may be required for individual transactions. Thus, it appears that while automatic uplinks and updates may be preferred as a default condition, it must also be possible to override this option to permit the controller to inhibit the uplink or the NAS update.

Comments recorded from the preference rating forms and the wrap-up questionnaire also indicated that the workload of the altitude assignment service would be reduced by placing an indication of transaction status in the FDB. This suggestion also supported the results of the first Mini Study in which an FDB display was recommended as an enhancement to the transaction list presented on the PVD.

3.2.4 Menu Text.

As with most of the other services, preference ratings for the menu text implementation were high. While all of the controllers rated the basic menu text concept as "good" or "very good" in the wrap-up questionnaire, two primary problems revealed in the debriefing discussions indicate that this service could be improved.

The wrap-up questionnaire results indicated that menu text would be a preferred method for issuing repetitive control clearances that are common to a specific sector. However, such clearances often require the controller to update NAS, and no provision for linking menu text uplinks to NAS was included in the current implementation. As shown by the PROSWAT scores, the requirement to reenter data significantly increased the projected workload for the text functions.

Integration of menu text transactions with NAS will probably require a capability to select the type of interaction needed in specific cases in order to provide flexible use of menu text for interim altitude assignments, speed, and heading changes, etc. To remain consistent with altitude assignment, menu text transactions should allow for selective updates of NAS and the FDB as well as uplinks.

A second problem with the menu text function noted by controllers in the debriefing discussions was the display of menu text message content in the Data Link transaction status list. In its tested form, the first six characters of a message were displayed. Because uplinks often consisted

of a verb (e.g., climb) followed by specific quantitative information, the transaction display provided insufficient message content to permit discrimination among different simultaneous transactions. In order to remedy this problem, it was suggested that standard templates be used for constructing menu messages. Such standardization would permit the computer system to extract essential data from the message and display it in the limited space on the list. Display of the assigned menu text message number in the status list was also a suggested solution.

3.2.5 Free Text.

PROSWAT and preference ratings for the free text function were statistically equivalent to those assigned to menu text. As expected, the controllers indicated that free text would be most suitable for non-control messages to aircraft and advisories because of its unrestricted format, and consequent inability to permit automatic error checking by ATC computers. In addition, the subjects felt that free text would be useful for communicating with aircraft experiencing emergency radio failures.

Primary improvements to free text suggested during the debriefing discussions were to increase maximum message length beyond the current 20 characters, and to provide an ability to store and retrieve free text messages for repetitive use.

3.3 IMPACT OF DATA LINK DELAYS, FAILURES, AND PARTIAL EQUIPAGE.

Data link failures, delays, and mixed Data Link equipage in the aircraft fleet were addressed during data collection in order to obtain an initial assessment of the potential impact of these primary operational issues on system performance. Using SWAT workload ratings as a criterion, the data indicated that neither the tested levels of Data Link transmission delays associated with antenna rotation (0- to 6-seconds), nor the occurrence of 10 percent failed uplinks (NAK's) significantly increased controller workload over current voice procedures in the simulation scenario used for this study. As noted earlier, these scenarios did not seriously tax the performance capabilities of the test controllers. Other results from the debriefing discussions and the wrap-up questionnaire also indicated that NAK's and system delays were not perceived by the subjects as significant impediments to Data Link communication.

Discussion of NAK's indicated that they would have little or no effect on work methods. One controller noted that since NAK responses were received faster than WILCO's, in this simulation, resending the data or making radio contact with an aircraft did not significantly increase transaction time. No clear preference was found among the subjects regarding an appropriate method for handling failed uplinks. Both voice and repeating the uplink were viewed as feasible alternatives, depending upon the time criticality of the message.

Debriefing discussions of Data Link transmission delays also indicated that the tested range of antenna rotation lags would not significantly impact work methods for the planned initial services. One subject felt that delays may encourage a beneficial increase in the level of anticipatory controller responses to air traffic situations. The wrap-up

questionnaire results also indicated that response times for Data Link were rated "somewhat good" or better by all of the subjects. Nevertheless, of the few least-liked features of Data Link mentioned in the questionnaire, potential response time delays were cited by some subjects, indicating a continued concern over this factor.

The SWAT ratings also revealed no significant impact of a mixed environment of Data Link equipped and non-equipped aircraft on controller workload in the present test scenario. Although the SWAT scores showed an apparent average workload increase for the partial equipage test condition, it was not statistically different than the baseline condition. The trend for an increase in workload may have been due to the increase in traffic load for the mixed equipage scenario. However, since some subjects indicated that the requirement to closely monitor for equipage indicators was a potential workload factor, this variable will require detailed examination during the operational evaluation study.

3.4 GENERAL DATA LINK RESULTS.

3.4.1 Data Link Displays.

No consensus was achieved regarding the number and types of transaction status messages that should be displayed in the transaction status list. Those subjects who preferred a minimal display felt that it was necessary to present only an indication of a failed transaction (i.e., NAK or NO REPLY). This choice appeared to be based on a desire to decrease display clutter by relying on the assumption that no indication would imply the completion of a successful Data Link transaction. The subjects who favored full display of transaction status (i.e., HELD, SENT, DELIVERED, WILCO, NAK, etc.) indicated that displaying the progress of a transaction would permit controllers to flexibly monitor Data Link and intervene as required.

As noted earlier in this report, the lack of a consensus on this design issue may require either a phased reduction of display content as Data Link is introduced to the field, or provision of both a detailed display of transactions in a list and a minimal display in the FDB.

The results of the first Mini Study showed that Data Link transaction status should be displayed in a central rather than a peripheral location (i.e., PVD rather than CRD). In addition, the subject controllers suggested that an FDB display may provide even greater improvements in the usability of this information. These preferences were reiterated by the subjects in the present study after working with a more realistic test scenario, which required increased reliance on the transaction display. In particular, the lack of an FDB display for the status of altitude assignment appeared to be one reason for its increased workload rating in comparison to the other services.

3.4.2 Data Link Controller Inputs and Procedures.

The results of Mini Study 1 showed that data entries required for sending uplinks and for managing the transaction displays should be minimized to reduce controller workload associated with Data Link. Therefore, automatic message preparation, uplinks, and deletion of completed transactions were recommended, when feasible. The results of the present study confirmed these earlier findings and extended them to the text services.

Controller experiences with the more complex test scenarios in this study showed that, like transfer of communication, altitude assignments could not be automatically uplinked under all conditions. Because of this, the controllers recommended that a method be developed for selecting a default destination for data entries (i.e., automatic uplink with the NAS update) with the capability to override this default condition and select alternate destinations (i.e., uplink only, NAS update only, FDB update, etc.).

A primary procedural opinion expressed by the subjects in Mini Study 1 was that the number of data entries required to complete Data Link transactions should be minimized. This preference was reiterated in the present with respect to the menu text function. Specifically, the subjects noted that the use of menu text for control clearances will require coupling of this service with the remainder of the ATC systems in order to avoid dual data entries. Thus, it should be possible for a menu text uplink to update NAS, the FDB, or both as required. The controllers also indicated that data entries needed for construction of menu text messages could be reduced by using message templates. These standard formats would require entry of only specific data (e.g., an altitude or speed) rather than the entire instruction.

The findings of the first Mini Study indicated that Data Link services should emulate current voice procedures in maintaining responsibility for ATC with the appropriate controller. Specifically, the results showed that the uplink of a new RF must be accomplished by the transfering controller rather than the receiving controller. The present results indicated that, in addition, Data Link eligibility should not be transferred to the receiving controller until the transfer of communication is completed and WILCOed. This modification will bring Data Link into alignment with current procedures by maintaining both voice and Data Link communications responsibility at the transferring controller's position until the complete transfer of control and transfer of communication sequence is accomplished.

This study presented the first opportunity to examine Data Link in a realistic ATC scenario which emphasized the delivery of the initial Data Link ATC services without redundant voice communication. While the subject controllers unanimously favored this situation, initial comments regarding the feasibility of a future "silent" Data Link environment were offered by some controllers during the final debriefing discussion. These subjects noted the potential workload problems associated with assigning both the tasks of monitoring aircraft separation and communication to the

visual system. While efforts to integrate Data Link transaction information into easily interpreted FDB display will undoubtedly reduce the demands of these dual tasks, consideration must be given in future work to the development of synthesized auditory Data Link displays or to the possibility that a rational mix of voice and Data Link communications will provide an optimal approach to future ATC.

3.4.3 The Impact of Data Link on the ATC System.

The results presented in the foregoing portions of this section support a number of requirements for modifications to the current implementations of the initial package of Data Link services. While these results suggest a number of changes and emphasize some open design issues, it should be noted that most of the modifications will be refinements to services already considered by the controllers to be positive contributions to the ATC system. In general, projected workload ratings were low and controller preference was uniformly high for all of the services and functions tested in this study. Furthermore, the wrap-up questionnaire indicated that Data Link continued to be viewed by the subjects as an extremely positive enhancement to the ATC system. Its effects on system capacity, controller workload, and pilot-controller communication were all rated highly. The controllers also indicated that Data Link will significantly enhance system efficiency and safety. Other general comments from the subjects emphasized the positive impact of Data Link on reducing RF congestion, traffic handling, and time available for additional controller tasks.

3.5 EVALUATION OF STUDY ADEQUACY.

Several comments were elicited on the wrap-up questionnaire regarding the methods and procedures used in this Mini Study. These comments were directed primarily toward enhancing the methodology for use in the operational evaluation study.

In general, the subjects felt that the realism of the simulation was good. However, five of the subjects commented that traffic levels should be increased in future research. This result, along with the relatively low SWAT workload scores assigned to all versions of the study scenario, indicated that controller task loading should be increased in order to fully exercise Data Link services in the operational evaluation study. Other related comments indicated that realism and task complexity would be enhanced by increasing the number of aircraft conflict situations in the scenario, and by avoiding the limitations of the DYSIM simulation mode in future studies.

4. CONCLUSIONS.

The results of the study presented in this report support several conclusions regarding the Data Link program and the design of the four Air Traffic Control (ATC) services that were investigated:

a. In agreement with the results of Mini Study 1, the Data Link system continued to be perceived by the subject controllers as an extremely positive enhancement to the ATC system. Working with more realistic air

traffic problems than those presented in Mini Study 1, the controllers concurred that the implementation of appropriately configured versions of the tested services and functions will significantly reduce radio frequency (RF) congestion while increasing system capacity, safety, and efficiency.

b. The conclusions of Mini Study 1 were upheld by the present results. The test subjects continued to support the use of centralized plan view displays (PVD) of Data Link transaction status, the use of Data Link without redundant voice communication, the necessity for downlinked confirmatory responses from pilots, and the use of automatic uplinks, where feasible, to minimize data entries.

c. Within the context of the ATC test scenarios employed in this study, perceived controller workload was unaffected by the substitution of Data Link procedures for current voice procedures. However, because of the limited task demands associated with the test scenarios, this finding will require confirmation in operational evaluation research using more complex air traffic problems and greater traffic densities.

d. Controller workload was not significantly affected by Data Link time delays attributable to antenna rotation lag, a 10 percent rate of uplink failures, or the simulation of an ATC environment in which only a fraction of the aircraft were equipped with Data Link. However, because of the limited complexity of the test scenarios and an apparent, but nonsignificant, trend toward increased workload when all three of these operational conditions were simulated together, this finding also will require confirmation during operational evaluation studies.

e. The design configuration for transfer of communication tested in this Mini Study produced the lowest projected workload ratings of the tested services and was highly preferred by the test subjects. The results also indicated that the primary flaw in the tested configuration was that the transfer of uplink authority occurred upon acceptance of a hand-off rather than after the transfer of communication had been completed.

f. The results for altitude assignment indicated that this service cannot be implemented in fixed automatic uplink mode. While automatic uplinks would be acceptable for a majority of cases, air traffic situations presented in the test scenarios revealed that an acceptable version of this service must permit the controller to selectively inhibit uplinks and control the destination for any altitude data entry (e.g., update NAS, update full data block (FDB), or both).

g. The menu text function was highly rated by the subject controllers and was perceived as a preferred method for issuing repetitive control clearances common to a specific en route sector. Because of this primary application, the controllers indicated that the function should be modified to couple menu uplinks to the remainder of the ATC system. The lack of this provision in the current study required additional data entries to update NAS, and negatively impacted projected workload ratings.

h. The subjects indicated that free text would be most suitable as a backup to radio communications and as a method for transmitting non-control messages and advisories. Increased maximum message length and the ability to store and retrieve free text messages were suggested as enhancements to this service.

i. Subject concerns about transaction display clutter and reducing the perceptual demands of monitoring Data Link activities reinforced the requirement to develop FDB displays for Data Link. Because some subjects preferred more complete transaction information than could be displayed in the FDB, a method may be required for providing both minimal transaction status in the FDB and a full list display elsewhere on the PVD.

j. The results of the study showed that, although simultaneous uplinks, NAS updates, and FDB updates are preferable in many situations, ATC practices require that it be possible to selectively control data entry inputs. One approach would allow simultaneous uplinks and system updates as a default condition, with the capability to inhibit the automatic uplink, the NAS update, or the FDB update by adding appropriate prefix codes to the data entry. For the initial package of Data Link services, such a modification is needed primarily for altitude assignment, but may be required as a general feature for the majority of future service developments.

5. RECOMMENDATIONS.

The results and conclusions derived from this study formed the basis for the recommendations listed below. These recommendations are intended to guide design modifications to the initial package of Data Link air traffic control (ATC) services, and to identify issues relevant to the conduct of future controller evaluation research on Data Link applications. All recommendations should be considered as supplements to those recorded in the Mini Study 1 report (Talotta, et al., 1988).

a. The transfer of communication service should be modified to transfer uplink authority to the receiving controller only after the transfer of communication has been completed and WILCOed by the aircraft pilot.

b. The altitude assignment service should provide for a choice of both automatic and manual uplinks by service delivery. In addition, this service must provide for selective control of updates of NAS and the full data block (FDB) indication of assigned altitudes.

c. In order to make menu text usable for the delivery of primary control instructions, this service should be coupled to the remainder of the ATC system so that uplinks can automatically update NAS, the FDB, or both.

d. Free text should be enhanced by increasing the maximum message length and by providing a capability to store and retrieve messages for later use.

e. The development of FDB displays of Data Link transaction status should be given high priority in the further refinement of the initial service package. These displays should be designed to provide an easily interpreted indication of key transaction states (i.e., SENT and FAILED), and should supplement rather than replace the transaction status list.

f. High priority also should be assigned to the development of flexible control over keyboard and trackball data entry inputs. Provisions should be made to allow selective control of NAS updates, FDB updates, and uplinks. To minimize data entry requirements, this modification should be designed with default destinations covering the majority of requirements for each service.

g. In order to identify any remaining limitations of the Data Link service designs during operational evaluation studies, emphasis should be placed on the development of complex ATC scenarios which closely approximate the task demands experienced by en route controllers in field situations.

h. Future operational evaluation research should include a further examination of the impact on controller performance and workload of Data Link transmission delays, uplink failures, and mixed equipage environments.

6. REFERENCES.

Talotta, N., et al., Controller Evaluation of Initial Data Link Air Traffic Control Services: Mini Study 1, Final Report, FAA Technical Center, DOT/FAA/CT-88/25, 2 Vols, 1988.